LONG DISTANCE TRANSMISSION

FOR

LIGHTING AND POWER.

BY

CHARLES F. SCOTT.

A Paper read at the General Meeting of the American Institute of Electrical Engineers, Chicago, Ill., June 7th, 1892.

(Reprinted from Vol. IX of the Transactions.)

Digitized by the Internet Archive
in 2017 with funding from
This project is made possible by a grant from the Institute of Museum and Library Services as administered by the Pennsylvania Department of Education through the Office of Commonwealth Libraries

https://archive.org/details/longdistancetran00scot

A paper presented at the General Meeting of the American Institute of Electrical Engineers, Chicago, Ill., June 7th, 1892, Manager Leonard in the Chair.

LONG DISTANCE TRANSMISSION FOR LIGHTING AND POWER.

BY CHARLES F. SCOTT.

The public interest in electrical subjects is continually sustained by the announcement of discoveries and projects which border upon the wonderful and extreme. In power transmission, one of the most inviting and promising fields, popular expectation often rises to operation over distances and at pressures which exceed the limits of commercial engineering. But many schemes which are readily planned with glowing outlines to accomplish wonderful results are defeated by difficulties encountered in details and unforseen obstacles.

The test of practical operation in long distance transmission has been applied in but few cases, and the severe test of continued operation over a considerable length of time is of rare occurrence. The latter is the crucial test, and its commercial significance gives it the highest importance. The continued and successful operation of one plant for a year, under extreme conditions of situation and service, is of higher value in testimony to the practical development and possibilities of electrical work than many elaborate projects, or the operation of novel apparatus for a short time.

It is with this idea in mind that a description is here to be given of two plants, one for lighting and the other for the transmission of power. The conditions which have been met include a very considerable distance, extreme difficulties of climate and roughness of country, exacting requirements in continuity of service, and a pressure above that ordinarily used in the class of machines employed. The plants to be described are the first of their type installed in this country, and the apparatus in the power plant is of a kind that has not been heretofore used. The type and construction of the machines, and the arrangement of apparatus are new in many particulars, and as they have contributed largely to successful operation they will be described with some minuteness. Alternating current machinery is employed, constructed by the Westinghouse Electric and Manufacturing Company, the pioneer company in alternating work in this country.

The lighting plant was first installed. It is operated by the Willamette Falls Electric Company, of Portland, Oregon. The general requirements are those which electrical transmission is admirably adapted to meet. Portland, a city marked for its prosperity and rapid industrial growth, has not the great advantage of proximity to developed coal fields, so that power, the fundamental requirement for industrial activity, cannot be obtained cheaply from this source. Another supply of energy, however, is found in rich abundance. The falls of the Willamette river at Oregon City, in the combined points of size, accessibility and nearness to the seaport, are unequaled. These falls, estimated at from 200,000 to 250,000 H. P., are about thirteen miles from Portland, and it requires but a moment's thought to appreciate the value of an agent which can make this power available in the city.

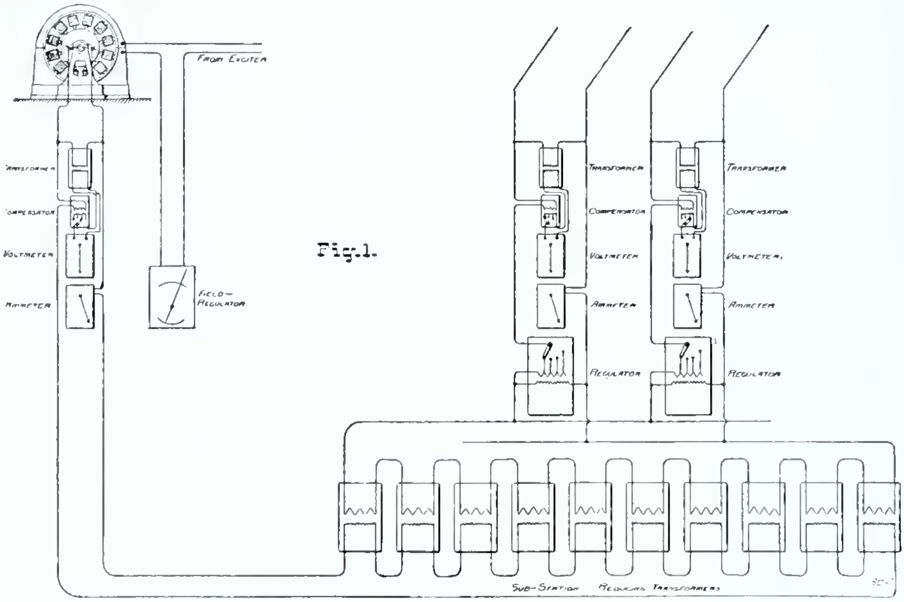
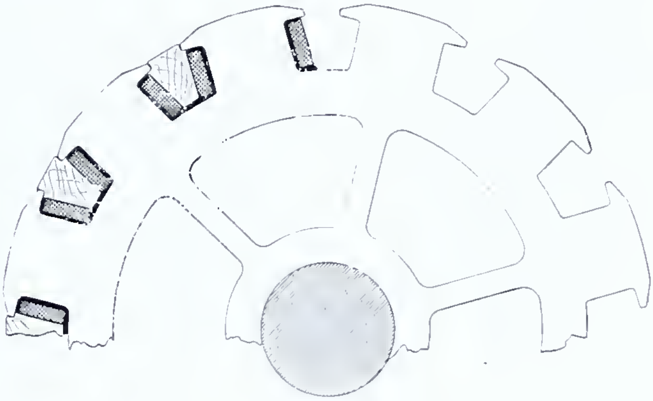


Fig. 1.

Lighting Plant at Portland. Diagram of Apparatus and Connections.

The Williamette river is about one-quarter of a mile wide, and the fall is about 40 feet. The present station is located on an island at the middle of the river. Victor wheels of 300 H. P. are geared to horizontal shafts, from which the dynamo belts pass to an upper floor at an angle of 45 degrees. Two alternating current dynamos for incandescent lighting are driven by each wheel. The current at a pressure of 4,000 volts, passes directly to the line of No. 4 B. & S. wire, which is carried on ordinary double-petticoat glass insulators across the level country to a sub-station in Portland. The current is received at 3,300 volts by transformers in the sub-station and is reduced to 1,100 volts, for distribution by various circuits through the city to ordinary transformers, by which it is reduced to 50 or 100 volts.

Fig. 2.



Section of Armature Showing Iron Disk with 3 Coils in Place.

When the apparatus was designed, it was not considered practicable to generate 4,000 volts with the ordinary type of machine, in which the wire is wound upon the surface of the armature on account of the difficulty of insulating for more than 1,000 or 2,000 volts. The work was undertaken with a new type of armature, which is specially noteworthy, as it has rendered high potentials practicable in a machine of simple construction.

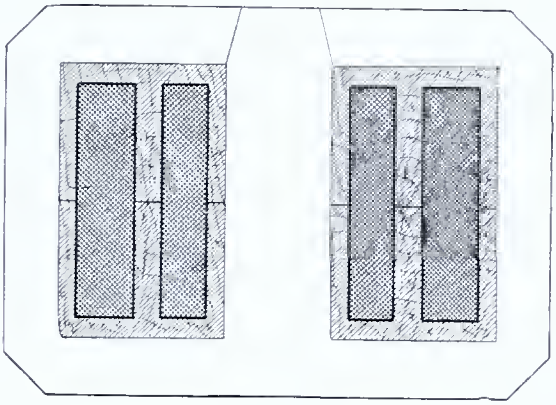
The field of the dynamo is of the ordinary type of alternating current machine in use in this country. The casting is circular in form, with 12 inwardly projecting poles of laminated iron, on which the field coils are placed. This type of machine combines simplicity with rigidity and strength, as both bearings and the lower field are in one casting.

The armature is built up of laminated disks, which are punched with 12 T-shaped teeth. The armature coils are wound in a lathe, are carefully taped and insulated, and are then placed over the teeth and sprung in under the projections. The space between adjacent coils is filled by a block of wood, which holds them in place securely. This form of construction gives all the advantages of machine winding over hand work, allows ample insulation between coils and core, protects the coils from mechanical injury, holds them in position without the use of band wires, and makes the replacing of a damaged coil comparatively simple. The field current is supplied from a direct current machine, and the main current is taken from two collecting rings on the armature shaft. The reducing transformers are placed in a vault in the sub-station at the city. They are arranged in banks, or units of ten. Each bank is supplied by a separate dynamo, and has a capacity of 1,250—16 C. P. lights. The coils of the transformers are separately wound and taped, and are separated from one another and from the iron by strips of wood. The primaries are connected in series for receiving 3,300 volts, and the secondaries are in series for delivering 1,100 volts, so that there are 330 volts in the primary, and 110 volts in the secondary of each converter. This method of connection throws small differences of potential in any single coil and permits the use of conductors of good size. The necessity for special insulation is between the coils, where there is ample room for placing it. A transformer may be readily cut out of circuit by short-circuiting its terminals, and in case of an accident in which a coil becomes short-circuited, the E. M. F. on that transformer disappears and the others are called upon to do a larger share of the total work without interfering with service. The efficiency of the transformer at full load is 96 per cent.

The operation of the system is simple. The voltmeter or potential indicator is supplied by the secondary of a converter reducing in the ratio of 30 to 1. In the voltmeter circuit there is placed a compensator, which is a small transformer with its primary in series with the main circuit, and its secondary in series with the voltmeter circuit, and connected in such a way that the compensator pressure, which is proportional to the main current, is opposed to that of the converter. The compensator is so adjusted as to introduce into the voltmeter circuit a counter E. M. F. proportional to the loss in the conductors, so that the voltmeter indicates the potential at the distant end of the line.

The compensator effects the same result as pressure wires run from the point of supply back to the station. The E. M. F. at the dynamo is adjusted for each load by regulating the field current so that the voltmeter shows the proper indication, thus keeping the pressure at the sub-station constant at 3,300 volts. The pressure at the dynamo is slightly in excess of this at light loads, and is increased to 4,000 volts at full load, to cover the loss of transmission. The secondary current from the reducing transformers is treated as if it were received directly from a dynamo. On each supply circuit from the station there is a voltmeter with a compensator set for the loss in this circuit. The exact adjustment of E M. F. on a circuit is made by a regulator, consisting of a transformer with its primary connected directly across the main terminals, and a secondary divided into small sections, each having an E. M. F equal to one per cent. of the primary. Any number of these sections may be placed in series with the supply circuit, thus varying the E. M. F. at will. This form of regulator is of high efficiency, as it converts but a small percentage of the total energy, and the loss is a small fraction of this percentage.

Fig. 2.



Section of Transformer Showing Iron Plate and Primary and Secondary Coils Surrounded by Wood.

The simplicity of the system, and the perfection of its operation, both from theoretical and practical standpoint, are noteworthy. The electrical system receives mechanical energy, converts it into electrical energy, in a form suitable for transmission over a distance too great for other agents, and by the simplest form of conductor, and transforms it to a pressure suitable for commercial lighting. And yet, in the whole system, there is but one element in which there is mechanical motion, and that motion is simple revolution. The only wear and friction is in the dynamo, and its bearings are large and easily lubricated. The one point at which the high-tension conductors need be exposed is at the dynamo, where the brushes and fittings are of the simplest sort. The line does not deteriorate by carrying current, and as a piece of apparatus the transformer, in simplicity of construction and operation, is unrivaled.

The plant was first installed with two incandescent machines and started nearly two years ago. Since that time, five additional machines have been added, so that there are now seven, each with a capacity for supplying 1,250-16 C. P. lights, in Portland. The total capacity is 8,750 lights. The dynamos run admirably. There was one night when several armature coils were burned out, which was attributed to an iron wire falling across the main line and connecting several of the circuits, grounding them. Otherwise there have been no difficulties to speak of with regard to the operation of the machines. The superintendent of the plant states that the line has given very little trouble, much less than would ordinarily be expected from a city line. He also says, that "the converters in the sub-station have not given one minute of trouble, and have not cost one cent for repairs." One explanation of the success of the plant is the intelligent policy of the general manager, in harmony with his statement that, "It is not the first cost which counts, but the cost of throwing out and replacing apparatus."

The same policy has happily governed the installation of the second plant to be described—the power plant. This is located near Telluride, Colorado, and is owned by Mr. L. L. Nunn. The Gold King mill requires power for operating its crushers and stamps, and fuel can come only from long distances at enormous costs. A few miles from the mill there is a water power, but the country between the two points is steep and rough, and for many months in the year is covered with snow. Electricity is the one means of getting the power from its source to the mill. The conditions are of the most favorable character for demonstrating the value and possibility of electrical transmission.

In this plant a Pelton wheel receiving water through a two-foot steel pipe, under a head of 320 feet. drives an alternating current generator. The current is carried over a line of bare wire to the mill, which is nearly three miles distant, and drives an alternating current synchronous motor of 100 H. P. The generator and motor are machines of the same size and form of construction as the dynamos at Portland, already described, and differ from these only in some minor modifications.

The generator is provided with a composite field winding. A part of the magnets are excited by direct current from a separate machine, and the rest are excited by a current from the generator armature, which is proportional to the main current and is commutated by the equivalent of a two-part commutator. The adjustment is such that the E. M. F. on the main terminals rises as the current delivered by the machine increases, compensating for line losses and keeping the pressure at the motor 3,000 volts. The speed is 833 revolutions, giving 10,000 alternations per minute. The switchboard and regulating appliances are similar to those in the station at Portland. Ordinarily no adjustment is required after the machine is started, and the

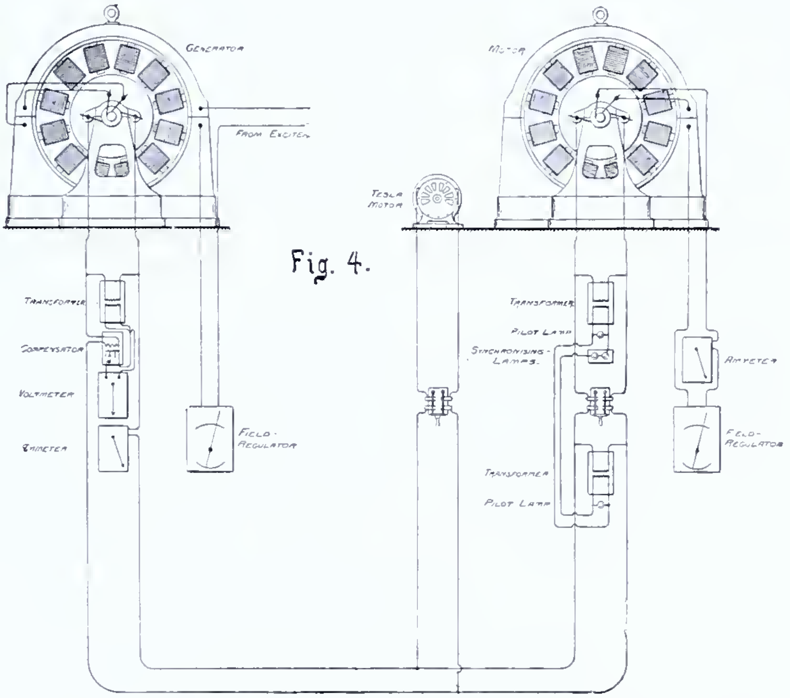


Fig. 4.

Synchronous Motor Plant at Telluride. Diagram Showing Apparatus and Connections.

attendant has little to do besides looking after the mechanical running of the apparatus.

The motor is similar to the generator except in the manner of exciting the fields. The field current is obtained, not from a separate machine, but from a second winding parallel with the main coils around the teeth of the armature. This current is commutated and passes through the field coils. The motor, as already stated, runs in synchronism with the generator, and although the general theory of the synchronous motor is well known, it may be briefly outlined. If the terminals of two alternating current machines giving the same number of alternations per minute be connected together, and one be driven by an engine or other source of power, the second will run as a motor and will do work. The impulses of E. M. F. which are generated in each machine occur simultaneously and are opposed in direction, so that only a small current flows through the circuit joining their armatures. As the motor is loaded, its armature is held back slightly and its impulses of E. M. F. do not exactly oppose those of the generator. This causes an increased current to flow which prevents further change in the position of the motor armature and holds its speed in synchronism with that of the generator.

A motor of the synchronous type requires an auxiliary device for starting, which, in the present plant, is a small motor—a special modification of the Tesla type. This has a laminated field with inwardly projecting poles, on which coils are placed which receive current directly from the main circuit. The coils on the revolving armature are short-circuited. There is, of course, no commutator or collector, nor is there any exposed contact or auxiliary apparatus except the switch. This motor comes quickly to its normal speed and then has ample capacity for bringing the armature of the large motor up to speed. Both of the machines are belted to a countershaft, and the ratio of the pulleys is such that the speed of the large motor is a little greater than that of the generator. The large motor is then excited and runs as a self-exciting alternating current dynamo at the normal E. M. F. of the circuit. The small motor is then switched off and the speed of the large machine gradually falls until it is approximately equal to that of the generator. The relation between the speeds of the two machines is indicated by the fluctuation in the intensity of lamps, which are connected in series with the secondaries of two converters, whose primaries

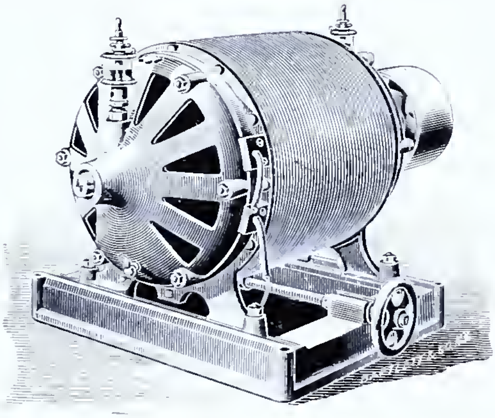

BARTLETT & CO. N.Y.

Fig. 6—Tesla Starting Motor.

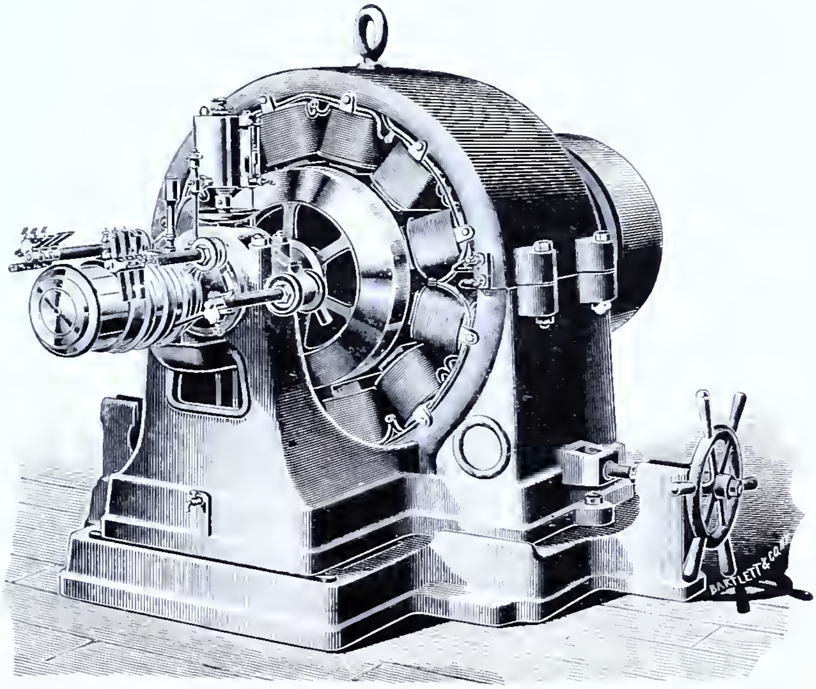
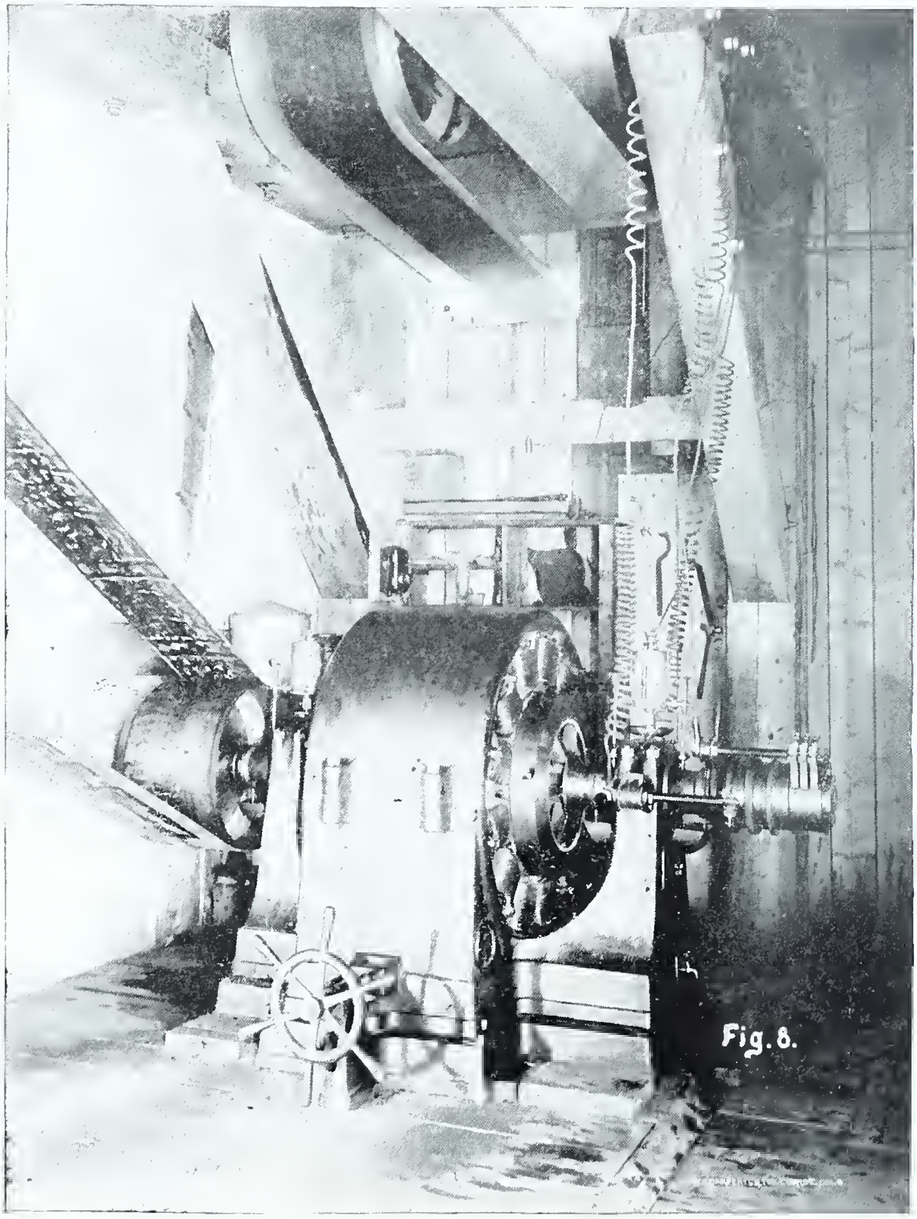

BARTLETT & CO. N.Y.

Fig. 7—Machine Used as Generator and Motor at Telluride.



The Synchronous Motor in the Gold King Mill.

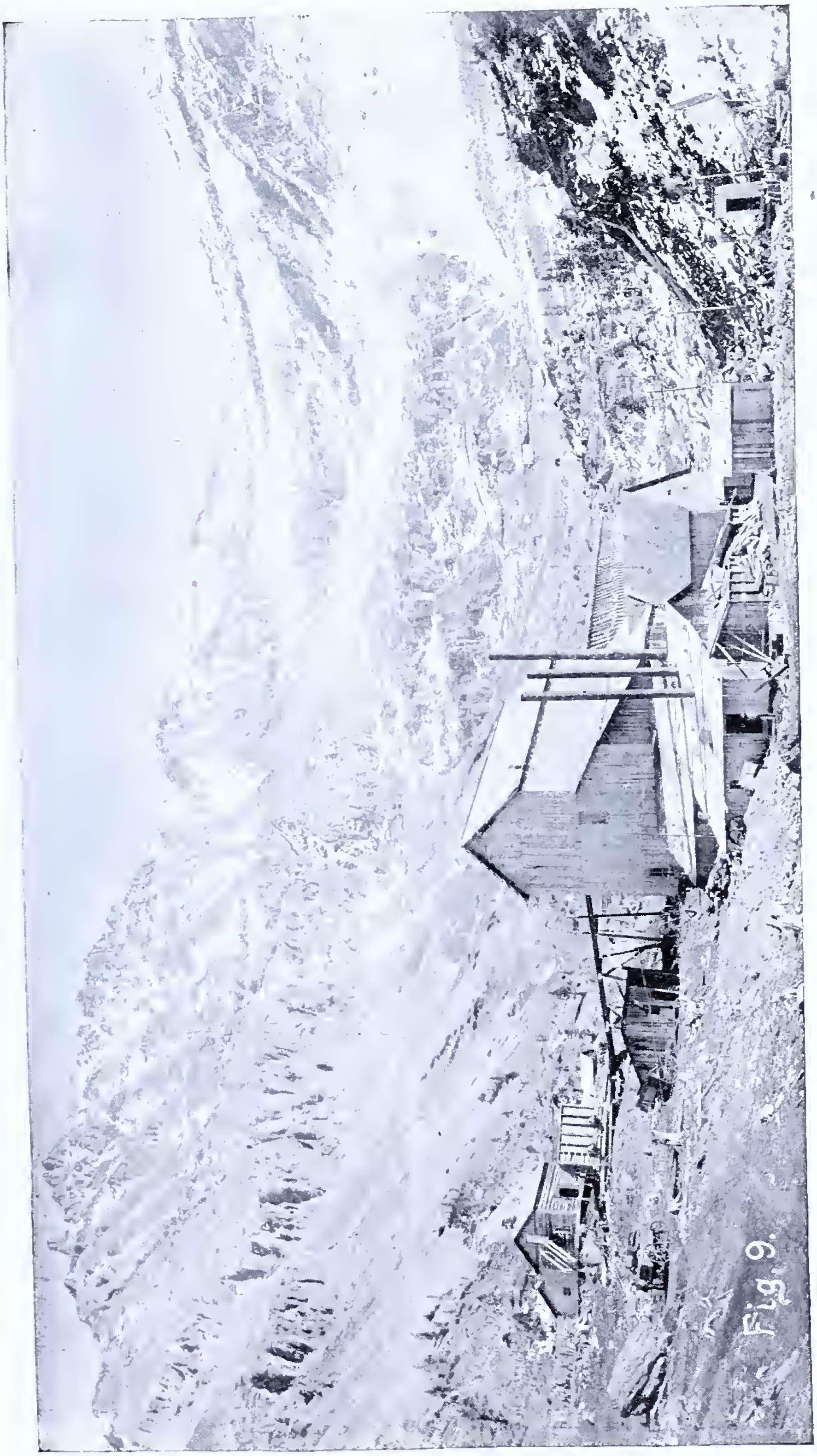
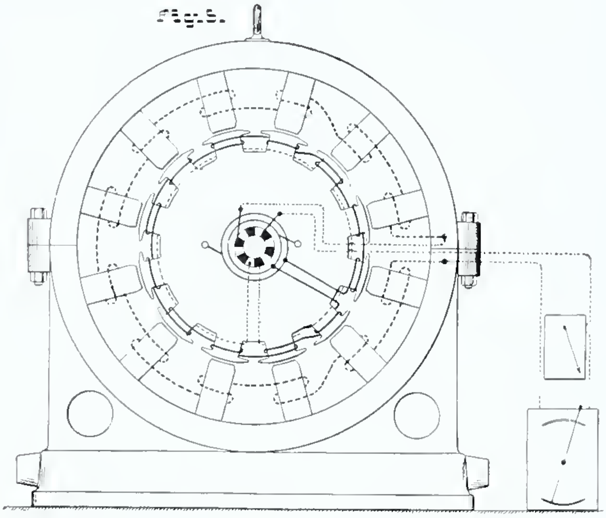


Fig. 9.

View of Gold King Mill, Illustrating Character of Country across which Pole Line is Run.

are connected with the generator and motor respectively. When the E. M. F's of the two machines are in the same direction, current will pass through the lamps, and when they are opposed there will be no current. If the motor is running a little faster than the generator, its E. M. F. will be in the same direction as that of the generator at one moment, and will be opposed at the next moment, causing a corresponding variation in the intensity of the lights. At the time of slow variation and proper phase relation the machines are connected by closing the switch. The small motor is disconnected by its friction clutch and comes to rest, and the load is then thrown upon the large motor by a second clutch. The operation of starting requires but one man, and is accomplished in about two minutes. The rheostat in the field circuit is adjusted to give the proper field current as indicated by the ammeter. This is done when the motor is started and it may then run indefinitely with varying loads without requiring any adjustment whatever.

Fig. 5.



Synchronous Motor. Diagram Showing Windings.

When the motor is running, the only things to be cared for are the brushes and the bearings. The high tension brushes — the only point besides the switches where the light tension is exposed—will run for a week without adjustment, the exciter brushes run without sparking and the lubricatian of the bearings is well provided for. The construction and operation of the motor is strikingly simple in comparison with the steam engine, which it replaces, with its many moving parts and intricate motions.

A few points illustrating the characteristics of the synchronous motor may be mentioned, as they are of both theoretical and practical interest. The connection of the motor to the generator is not a delicate operation. If the motor is running above synchronous speed at the time of connection with the generator, it instantly adapts itself to the proper speed. If the motor speed is slightly lower than that of the generator, it may fall into step when the switch is closed, but if it be running considerably slower it will not come into synchronism, but will further decrease in speed. When this occurs, the switch of the large motor is opened and that of the starting motor is closed, bringing the machine up to full speed again without any injury to the apparatus. If the E. M. F. upon each of the machines before connecting them be 3,000 volts it will remain unchanged when they are connected. If the field current of either machine be increased, the E. M. F. will be raised, but the field current of the other machine may be lowered and the resulting E. M. F. made equal to 3,000 volts. The current flowing between the machines depends upon the relative field charges, and is least, whatever the load may be, when the two machines are equally or very near equally excited. The field current of either machine may be made zero, and the motor will still run, but with greatly reduced capacity. In a test with machines of a smaller size the E. M. F. was 2,000 volts when the two field charges were equal. When the field charge of either machine was cut out it fell to 1,200 volts and the current increased very considerably.

The explanation of the fact that the two machines may run together with widely differing field charges is easily understood when the extra flow of current at that time is taken into account. If the field charges are different, the E. M. F. tends to be different also, and a current flows between the generator and motor, which is of such phase that it tends to strengthen the weaker field and to weaken the stronger one. Thus, when the tooth of the motor is in front of a field pole, the current flowing at that time is in such direction as to weaken or strengthen the field as may be required to make the E. M. F. equal to that of the generator. Difference of phase between E. M. F. and current has an effect upon the regulation of a dynamo, which is easily shown by changing the character of the load. If a dynamo with a constant field charge is used for carrying an ordinary load of incandescent lamps, a certain drop in E. M. F. will result. But if the same current be delivered to an inductive resistance, such as a coil of wire, the starting motor, or a synchronous motor, when its armature is at rest or its field is not charged, the drop in E. M. F. will be considerably greater than with lamps. On the other hand, when the generator is supplying a synchronous motor running under normal conditions, the drop in one test was about half that which resulted from the same current to incandescent lamps. The current to the motor when running without load is quite small and increases in proportion as the load is added. With any definite load the current between the machines, as already pointed out, depends upon the relative field charges of the machines as well as upon the E. M. F.: but there is, however, a considerable range through which the field charges may be varied without materially affecting the current. If the load on the motor be increased to about twice its rated capacity, it will fall out of synchronism and come to rest. The current, however, is held back by the self-induction of the motor armature and is not sufficient to cause immediate injury.

An efficiency test of the motor was made before shipment by driving a dynamo which was loaded. The current and E. M. F. received by the motor and delivered by the dynamo were measured and an allowance made for the loss in the dynamo. The full load efficiency in this way was found to be 93 per cent. In a test upon smaller machines of similar type the efficiency of the motor at full load was found to be 91.5 per cent. The efficiency of the synchronous motor system, leaving out loss in conductors, but including losses in generator and motor, in the plant for the delivery of 50 H. P. was found to be 83½ per cent. at full load, and 74 per cent. at half load.

Full load may be thrown on the motor suddenly. In the Gold King mill the stamps, which are operated by the motor, are usually left raised when the plant is stopped, in order to avoid the extra strain of lifting them when the plant is started. It sometimes happens that the stamps are left down and the motor is required to raise them all at once. When the clutch is thrown in, the current indicates that the load is considerably above the normal capacity of the motor, and yet it is started without difficulty or apparent strain.

The excellent current regulation with different loads, the tendency of the machines to normal adjustment when there is ordinary variation in the field currents, the small liability to injury when the motor is greatly overloaded, the high efficiency and ease of attendance, are points of great value in the practical operation of the system.

The pole line runs from the power station up the mountain to a height of 2,500 feet, and then crosses a rough but comparatively level country to the mill. The line at some places is at an angle of 45 degrees, and many of the poles had to be set in solid rock. The surface of the snow in winter is occasionally at a level with the tops of the poles, and parts of the pole line are practically inaccessible during some months of the year. This region is peculiarly subjected to lightning discharges, and special precautions are necessary to protect the apparatus. In one instance there were 42 discharges of the lightning arresters in as many minutes.

The plant was started for regular work in June of last year. An accurate record was kept from the middle of July to the first of May, showing the actual number and the length of the delays caused by electrical machinery. During these nine and a half months the system was in regular continuous operation six and a half days each week, with but few intermissions. The difficulties which were encountered were insignificant in amount and have resulted, not from any fundamental difficulty in the system, but have been caused by incidental defects or accidents which usually indicated their own remedy. The stops due to the electrical machinery resulted from a variety of causes and comprised the replacing of an armature coil damaged by lightning, renewing of fuses, fixing loose contacts, the examination of the line after a storm, and sundry other slight mishaps. The aggregate time lost on account of the electrical apparatus was, by actual count, less than 48 hours during three-fourths of a year. A recent report from the superintendent of the plant covering the ime from December 13th to May 1st, shows that the plant was running 127 days with a loss of 19¾ hours, or, as he puts it, an average of about nine minutes in a day of 24 hours. Although the plant was generally shut down each week for 12 hours on Sunday, this was not practicable during a part of the winter, and the motor on one occasion was run continuously for 27 days without any stop whatever.

Such a record as this, with a new type of machinery, in a country where line construction and maintenance are peculiarly difficult, with practically continuous service, with attendants who were not electricians, with a high voltage, a considerable distance and large power, places transmission by the alternating current synchronous system beyond the stage of experimental trial and gives it the stamp of commercial success.

This success is confirmed in a substantial way by the immediate extension of the plant. A 50 H. P. motor is now being installed at a mill a few miles from the Gold King. An order has been entered for a 750 H. P. generator to be located in the power station, and a 250 H. P. motor for operating a mill about 10 miles distant. Lighting at Telluride, eight miles from the station, which has been heretofore done on a small scale on a circuit from the power generator is being extended. *

The large generator is a new design, and is notable as it has more than three times the capacity of any alternating current dynamo previously made in this country. Two machines of this size have been running for some months for incandescent lighting in St. Louis.

This dynamo is of a type similar to the machines at Portland and Telluride. The field has 28 poles, requiring a speed of 570 revolutions for 16,000 alternations, the conditions of running at St. Louis, and 357 revolutions for 10,000, as it will be operated at Telluride. The armature has T-shaped teeth, as in smaller machines. The diameter of the armature is slightly over four feet and its length is about two feet. There is a third bearing at the end of the shaft outside of the pulley to relieve the other bearings from the severe strains resulting from belt tension. The total height of the machine is eight feet and its weight is 40,000 pounds. The electrical efficiency at full load is over 95 per cent.

The extension of alternating current working, both for lighting and power, by the use of larger machines is therefore already provided for.

The extension to greater distances is largely a question of E. M. F. Nearly everyone is familiar with the rapidity with which the cost of copper diminishes as the voltage is increased.

If the cost be $100 with 500 volts, it will be $25 at 1,000 volts, and $1 at 5,000 volts. The higher the tension, however,

---

* NOTE:—May 1893. Since this paper was read the 750 H. P. Generator, the 50 H. P. Motor and the 250 H. P. Motor have been installed and put in operation. The order has been placed for an additional 75 H. P. Motor. A letter from the engineer of the plant, dated April 20th, 1893, contains the following: "The generator runs very nicely indeed. . . . . . The motors are running very satisfactorily. The 250 H. P. motor is running very nicely at the present time. The 50 H. P. motor has been running about a week since the winter shut-down, and the 100 H. P. motor (which has been idle during repairs to the mill) is expected to start within two weeks. When we get the 75 H. P. motor and start it we will feel that we have quite a system in operation."

the greater the difficulty and cost of construction and the greater the liability to accident with apparatus and line. There are a few points in connection with this subject which may be noted without entering into a general consideration of it.

The smallest size of wire that can well be used for line work on account of its mechanical strength, is about No. 6 B. & S. This wire will transmit with 20 per cent. loss 100 H. P. 10 miles at 4,000 volts, or twice the power half the distance. Unless these distances or powers are to be exceeded, an increase in pressure would result in no saving in copper but simply in a less line loss, which is already not excessive.

The use of 4,000 volts at the motor and a line loss of 20 per cent. requires an outlay for copper of only about 10 per cent to 15 per cent. of the total cost of the plant when the distance is 10 miles. Unless, therefore, the cost of copper is to bear an insignificant proportion of the total cost it is unnecessary to exceed this pressure unless the distance be greater than about 10 miles.

These simple considerations show that pressures practically the same as those employed in the plants which have been described are ample for considerable distances. The same type of apparatus which has been successful in them is available for larger capacities. The fundamental elements required for electrical transmission in a very wide range of cases have therefore been tried and their succes demonstrated.

For considerably longer distances, where pressures higher than about 5,000 volts are required, good practice indicates the use of transformers for raising the pressure at the generator and reducing it at the motor, similar in general to those employed at Portland. The increased pressure thus available greatly reduces the cost of copper required, and this reduction must, of course, be more than sufficient to cover the cost of the transformers.

The prime requisite in a system for power transmission or distribution is simplicity. In this point electrical apparatus is scarcely to be compared with any other class of machinery. There is a marked difference, however, between the classes of electrical apparatus. In direct current machines the commutator is the characteristic feature. It is expensive to make, to maintain, and to renew. The insulation of the armature is much more difficult, because it is necessary to connect a hundred points in the winding to exposed pieces. The commutator is the part requiring the most careful adjustment and attention both in construction and operation, and yet it is ordinarily the source of more difficulty than all other causes combined. It is, moreover, the principal element which limits the E. M. F. at which this class of apparatus may be operated, and, in order to secure the advantages of a high E. M. F., systems are planned in which the generator and motor is each composed of three or four distinct machines to be run in series, thus avoiding an excessive E. M. F. on any single commutator at the expense of many machines and multiplied parts. The alternating current machine substitutes for the commutator the simplest kind of contact—brushes sliding on plain rings.

The alternating current is anomalous. For years it had little place in literature and less in practice. Theoretically, it is intricate and complicated, and the earlier difficulties in its application caused it to give way to direct current. But the direct current is reaching its limitations in conditions which alternating current apparatus readily meets. The alternating current motor has been one of the most complicated and difficult electrical problems, and yet the first large alternating current motor installed in this country excels direct current apparatus in simplicity of construction and operation, in perfection of regulation, and handles with simple sliding contacts, running for a week without adjustment, a pressure which with commutators is impracticable.

There is another class of alternating current apparatus to which no reference has been made. The multiphase, or Tesla system, which has attracted much attention of late, possesses the characteristics of this type of apparatus, which readily adapt it for combining simple construction with the use of high pressures. There are also marked advantages in the characteristics of the motor which are of especial value where the distribution of power is to be combined with transmission. Motors of this class are self-starting with load, and may be run either as synchronous motors or with one winding short-circuited and no commutator or brushes. The latter is the ideal motor in point of mechanical construction.

The simplicity and flexibility, and range of the alternating current system make its possibilities the sole dependence of the largest enterprises toward which the public and engineers are looking. The records of the plants at both Portland and Telluride, demonstrate that these possibilities are being realized, and that work in this field is fast passing from experimental investigation into practical electrical engineering.